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NUCLEAR FISSION AND HEAVY PARTICLES IN COSMIC RAYS

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/Figures are appended./

Nuclear fission and heavy cosmic ray particles are usually studied by the aid of photographic plates or Wilson cloud chambers. In 1945, N. S. Ivanova employed cylindrical proportional counters divided into two parts to study nuclear fission. The work to be described was carried on by means of similar proportional counters. The task undertaken in this work is the clarification of problems which remained unsolved in N. S. Ivanova's work /1/.

The counters used in the present work (Figure 1) are composed of cylinders divided into two parts by a 40-micron-thick aluminum screen. Each part is an independent counter. The screen thickness is selected so that extraneous alpha particles from radioactive impurities cannot penetrate from one half of the counter to the other half. There is a tungsten filament with separate leads stretched across each half cylinder. The ends of the counters are closed with small glass caps that are silver-plated outside and inside. The silver-plated surfaces serve as guard rings. The counters are filled with commercial-grade argon at a pressure of 410 millimeters of mercury.

The counters are graduated with the aid of an alpha-particle source soldered inside their caps. The source can be moved parallel to the filament. The sensitivity of the apparatus is controlled by measuring the number of impulses in each half of the counter when the RaD source is brought toward it a determined distance. Pulses from both halves of the counter are applied to the input tubes of a two-channel linear amplifier. The threshold of sensitivity of the apparatus is determined by the grid bias on the multivibrator which is inserted after three stages of linear amplification.

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To study the generation of nuclear fission in various substances, a cylindrical lead layer 35 millimeters thick is inserted inside certain counters. The counters with lead lining are hereinafter called "lead." Comparison of the number of double coincidences in aluminum and lead counters made it possible to form a judgment about the generation of nuclear fission in lead and aluminum.

Experiments with lead and aluminum counters were conducted at altitudues of 4,700 and 3,860 meters above sea level. The number of double coincidences was measured for various sensitivities of the apparatus. In order to explain the penetrating power of particles generating nuclear fission, the counters were placed inside a lead filter (Figure 2). Measurements were made alternately without the filter and under the lead filter, which assured equal sensitivity in these experiments. The results of experiments at 4,700 meters above sea level are given in Table 1.

Table 1

Sensitivity		No of Double Coincidences per Hr			
		Lead Counter		Aluminum Counter	
i_o Pairs of Ions	n	Without Filter	Under 10 cm of Lead	Without Filter	Under 12 cm of Lead
750	9	127 ± 11.3	84 ± 9.1	27.8 ± 2.7	34.2 ± 2.9
830	10	92 ± 4.4	65.3 ± 4.6		
910	11			25.6 ± 1.4	25.5 ± 3.6
1000	12	80.5 ± 4.3	56 ± 5.2		
1410	17	42.7 ± 3.1	37.5 ± 4.3		
1660	20	29.1 ± 1.5	23.2 ± 1.5		
1910	23	14.3 ± 1.1	17.7 ± 1.5		

Here i_o is the necessary minimum initial ionization in each counter half required to permit operation of the apparatus, and n is the minimum initial ionization expressed roughly in the number of relativistic particles with normal ionization. The results of similar experiments at 3,860 meters are given in Table 2 (Figure 3).

Table 2

Sensitivity		No of Double Coincidences per Hr			
		Lead Counter		Aluminum Counter	
i_o Pairs of Ions	n	Without Filter	Under 10 cm of Lead	Without Filter	Under 10 cm of Lead
660	8			41.5 ± 3.4	30.6 ± 3.4
750	9			24.1 ± 1.3	
830	10	69.4 ± 3	40 ± 6.3		
910	11			14.3 ± 0.9	
1080	13	37.0 ± 6.1	29 ± 5.4		
1310	17	27.8 ± 1.1	22.5 ± 1.2		
1490	18			9.9 ± 0.9	11.3 ± 2.7
1660	20	17.7 ± 1.2			
1910	23	10.7 ± 1.4	11.1 ± 2.9		

It follows from these experiments that the effect produced in a lead counter by nonfiltered radiation is 3 - 3.5 times greater than in an aluminum counter. If the particle spectra (distribution) coming from lead foil and aluminum and the "multiplication" of the particles in both those cases are assumed to be identical (this, in other words, is hardly likely to take place), then the effective cross section of formation of "stars" is 12 - 15 times greater in lead than in aluminum. This data is in good agreement with the results obtained by N. S. Ivanova who found a four-fold difference between the effect in lead and the effect in aluminum. Tables 1 and 2 show that the effect observed in an aluminum counter is produced almost entirely by penetrating particles, whereas in a lead counter at high sensitivities about 35 percent of the nuclear fission is produced by particles absorbed by the first 10 centimeters of lead. When the sensitivity is more limited, the role of these "soft" particles gradually vanishes. The ionized effect of generated particles amounts to 2 - 4 percent of the ionization of the hard cosmic ray component.

It may be seen from Tables 1 and 2 that the number of nuclear fissions increases rapidly with altitude. If the number of nuclear fissions is taken as 100 percent of the penetrating particles at an altitude of 3,860 meters, then 170 percent will be obtained for an altitude of 4,700 meters. The effect of nonfiltered radiation increases with altitude somewhat more slowly. To be exact, if the effect of nonfiltered radiation in a lead counter is taken as 100 percent for an altitude of 3,860 meters, then we shall obtain 153 ± 22 percent for an altitude of 4,700 meters. This indicates the increase in the role played by soft particles as the altitude of the place of observation decreases.

Thus, the effect of penetrating radiation grows more rapidly with altitude than the effect of soft radiation, whereas the soft cosmic ray component is known to increase with altitude somewhat faster than the hard component. If the curve of the number of nuclear fissions versus altitude, obtained by Wambacher and other /2/, is extrapolated, for altitudes 3,800 to 4,700 meters the curve will almost exactly coincide with our curve for nonfiltered radiation.

To clarify the nature of generating particles at an altitude of 4,700 meters above sea level, the following experiment was carried out: Besides 10 centimeters of lead, an additional 20-centimeter thick aluminum filter is placed over a lead counter (Figure 4). The additional filter is taken as approximately equivalent, in ionization losses, to a column of air between 4,700 and 3,860 meters above sea level (a column of air weighing 59.8 grams and one square centimeter in cross section).

Measurements under the filter for sensitivity control are alternated with measurements of the number of double coincidences without any filter. Results of measurements are given in Table 3.

Table 3

Sensitivity i_0 Pairs of Ions	n	No of Double Coincidences per hr under 10 cm Pb + 20 cm Al
830	10	54.5 ± 3.7
1080	13	41.6 ± 2.5
1410	17	32.1 ± 3.3
1660	20	24.3 ± 1.9

Table 4

Altitude (in m)	Filter under Counter	No of Double Coincidences (%)
3860	10 cm Pb	100
4700	10 cm Pb	169 ± 30
4700	10 cm Pb+ 20 cm Al	142 ± 24

The data on the increase of penetrating generating particles with altitude and their absorption by solid substances are set forth in Table 4 (Figure 5). This fact is hard to reconcile with the rapid increase in nuclear fission, well-known from many data and in good agreement with our results, that is, the fact that fission, especially during great ionization, is created by penetrating radiation.

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Table 5

Substances	A (atomic weight)	A 2/3	Effective Cross Section (sq cm)
Lead	207	35	$> 7.0 \cdot 10^{-25}$
Aluminum	27	9	$\simeq 1.5 \cdot 10^{-25}$
Air	14.5	5.9	$\simeq 2.1 \cdot 10^{-25}$

The approximate effective cross sections of absorption of penetrating generating particles, estimated from our experiments, are shown in Table 5.

It may be seen from this table that the effective cross section of absorption of penetrating generating particles for air was found to be greater than the cross section for aluminum. Hence, it follows possibly that penetrating generating particles are capable of decomposition.

From the rapid increase in nuclear fission with altitude it follows likewise that the ordinary mesons of the hard component cannot be generating particles.

Knowing (the absorption of generating particles is assumed to be due to nuclear fission) the effective absorption cross section for nuclear fission in lead, the number of nuclei per unit area of the counter wall, and the number of double coincidences recorded by the counter, one can evaluate the flow of generating particles S^{gen}. The flow at an altitude of 4,700 meters is shown to be greater than the flow of particles of the hard component, that is, $(s^{gen}/s^{hard}) > 1$.

Hence, it obviously follows also that no ionizing particles can be generating particles, since there is no place for them in the ionization of the hard component.

Therefore, on the basis of the experiments made, it is possible to assume that nuclear fission in cosmic rays is produced by particles possessing the following properties: (1) these particles react strongly with atomic nuclei (greater effective cross sections); (2) they are neutral; and (3) the flow of these particles at great altitudes is of the same order of magnitude as the flow of the hard component of cosmic rays.

These particles seem to decompose spontaneously. If this circumstance is confirmed by further experiments, it will mean that generating particles are not neutrons, but some sort of new neutral particles.

In conclusion, I wish to express my gratitude to Prof V. I. Veksler for directing the work and aiding in its accomplishment to V. L. Ginzberg, who pointed out many experiments to clarify the nature of a generating component, and to N. A. Dobrotin for his valuable advice and aid during the work.

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2. Stetter G., Wambacher, H., Phys. ZS., 40, 702, 1939

[Appended figures follow.]

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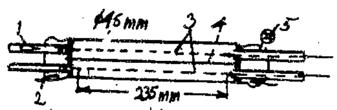

Figure 1. Double Proportional Counter

1. Source of particles. 2. Guard ring outlet. 3, Filament. 4. 40-micron-thick aluminum screen. 5. Drying chamber with sodium.

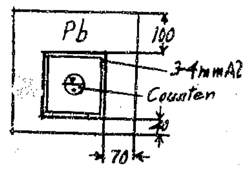

Figure 2.

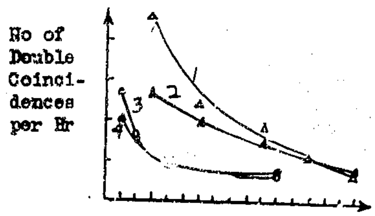

Figure 3. Lead Counter

1, Without filter; 2. Under 10 cm of lead. Aluminum counter: 3, Without filter; 4, Under 12 cm of lead.

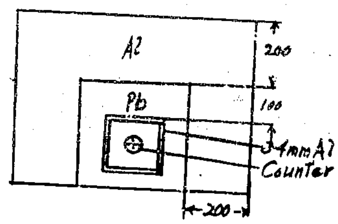

Figure 4.

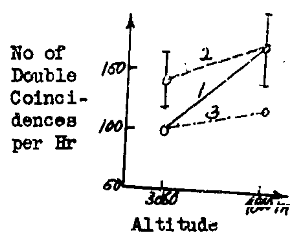

Figure 5.

1, Growth of stars. 2. Under 10 cm lead / 20 cm aluminum. 3, Growth of hard component (Azimov)

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